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Preliminary Study on the Influence of Visual Cues, Transitional Environments and Tactile Augmentation on the Perception of Scale in VR

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Abstract. Virtual reality (VR) is being used more and more as a way to easily visualize and share ideas, as well as a step in product designing. The initial study presented in this paper is part of a project for getting the general public involved in the design of new busses for Northern Jutland in Denmark, by using VR visualization. An important part of VR visualizations is the correct understanding of scale. Studies show that the perception of scale in VR undergoes compression compared to the real world. In this paper we test how additional visual cues, transitional environments and tactile augmentation in a VR environment can help with the perception of scale. We show that familiar visual cues can help with the perception of scale, but do not remove the compression of perception. We can further mitigate the problem by introducing transitional environments and tactile augmentation, but transitional environments provide a better perception of scale than tactile augmentation.

Keywords: Virtual reality (VR) · Scale perception · Visual cues · Tactile augmentation · Transitional environments.

1 Introduction

Virtual reality (VR) has become an important part in involving users during the design and testing process of manufacturing, before the final product is made. VR as a medium, allows for early and inexpensive public testing of products, resulting in a more rapid design process. This paper is part of a project to involve the populace in the design of new buses, before the final product is finalized. To make the process less time consuming and costly a VR visualization is selected. One of the main requirements for the project is to design the environment with a correct sense of scale and judgement of distances. This can become a problem because egocentric and exocentric distance perception in virtual reality gets affected by the compression of scale. In general, the estimated dimensions of virtual environments are about 74% of the actual modeled dimensions [1], [2]. It has been suggested that the cause of the compression is related to higher-level cognitive issues in the interpretation of the presented visual stimulus [3]

As humans perceive size and distances in many different ways, there are a variety of techniques used to estimate how big and how far away an object is in a scene. In this paper we present two experiment studies into how the user's perception of scale is influenced by three common factors:

1. Familiar objects as visual cues (VC) - the familiar size of an object influences the perceived size in agreement with the size-distance invariance. [4];
2. Transitional environment (TE) - the change between real and virtual world can help with immersion and the perception of the virtual environment [13];
3. Tactile augmentation (TA) - the introduction of additional modalities and the insertion of the human body in VR helps with scale understanding and immersion [5], [6], [7].

The results confirmed that the availability of objects with a familiar scale increases the accuracy of scale perception. Having both a transitional environment and tactile augmentation greatly reduces the compression of scale, with the transitional environment proven to have a greater influence than tactile augmentation.

2 State of the art

One way of decreasing the compression is through visual cues, such as binocular disparity, motion parallax and relative size. Loyala [9] found out that having multiple visual cues available helps explaining inaccuracies in dimension estimation in VR, especially for egocentric dimensions. Furthermore the findings indicates a trend that the accuracy of estimations rises with the level of cues available.

Another proven method is the introduction of a transitional environment. A replica of the real world can be made in VR and users can first start in that environment, making their transition into VR smoother and their sense of presence higher. Furthermore, gradually transitioning users from the virtual replica to a different scene, increases their presence in the real world [10], [13].

Finally, tactile augmentation can be created when a virtual environment mixes real-life physical objects with their artificial representations, resulting in the user being able to touch real physical objects while being inside a virtual environment [11], [12], [14]. Allowing the users to interact physically with the objects through both visual and tactile cues, is found to increase presence and immersion [6] [5].

In this paper we build upon these findings, by testing how combining these three elements can influence the perception of scale in VR.

3 Experimental Setup

As a basis for the experiments the virtual environment used is a 1:1 replica of the laboratory[1] (Figure 2c) where the tests are carried out. It was created by

[1] Model freely available from graphics.create.aau.dk

measuring the laboratory and modeling all of its interior and positioning it in the correct places. The VR system used is the HTC Vive, as it provides the possibility for easy movement tracking, as well as both controller and tracker support. For creating the testing application, Unity was used together with StreamVR, while the interior was modeled using Maya. An overview of each of the experimental environments is given below.

3.1 Familiar Objects as Visual Cues

The laboratory environment was used as the testing environment. The first experiment introduced six real-world objects - bottle of water, mug, coca-cola can, milk carton, pendrive and a tennis ball. Virtual objects are created by modeling real world equivalents in Maya and scaling them to absolute real world scale, except the tennis ball, which is the one that users would need to scale. They are then placed corresponding with their real-life position (Figure 1). The objects were deemed recognizable to the general public, as they represented items normally found in an office or home environment. All interactions are carried on with the use of the Vive controllers.

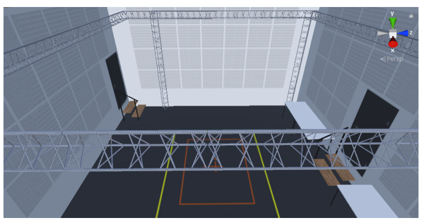
Fig. 1: The six modeled objects on a table in VR. The object are used for the first test - scaling the tennis ball correctly by using visual cues from the other objects.

3.2 Transitional Environment & Tactile Augmentation

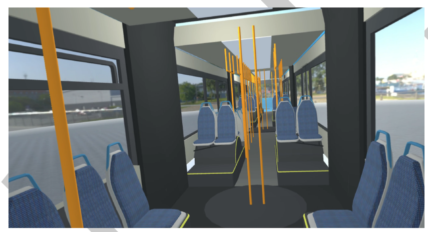
The laboratory environment is used as the transitional environment. The second experiment introduces a real world bus chair and pole 2a, which are remade in VR 2b, together with a bus model 2d, for test participants to walk around and interact with. The models are created in Maya, using real life images and sketches. The interaction with the environment are carried out using both the HTC Vive controller and a tracker for users hand. The modeled objects are also tracked using additional trackers.

(a) Real-world chair, with attached tracker at the end of the pole

(b) Render of the replica model of the chair



(c) The laboratory environment



(d) The bus environment

Fig. 2: The solution used a bus seat as a tactile augmented object and had two different environments

Because of the size of the bus, teleport points are used to move the user around, and from the transitional environment to the bus environment. Users can also move freely if needed. The outside environment was created with a 360 sphere textured with a simple real world location wrapped on the inside of the sphere. The outside environment was created with the intention of preserving the users focus on the inside environment of the bus, while still preserving the immersion of being inside a bus.

4 Experiments and Results

To evaluate people's perception of scale inside a virtual environment we designed two experiments. In the first one, the effects of familiar objects on the scale perception were assessed. In the second test, we tested the effects of Transitional Environment and Tactile Augmentation on the users' perception of scale.

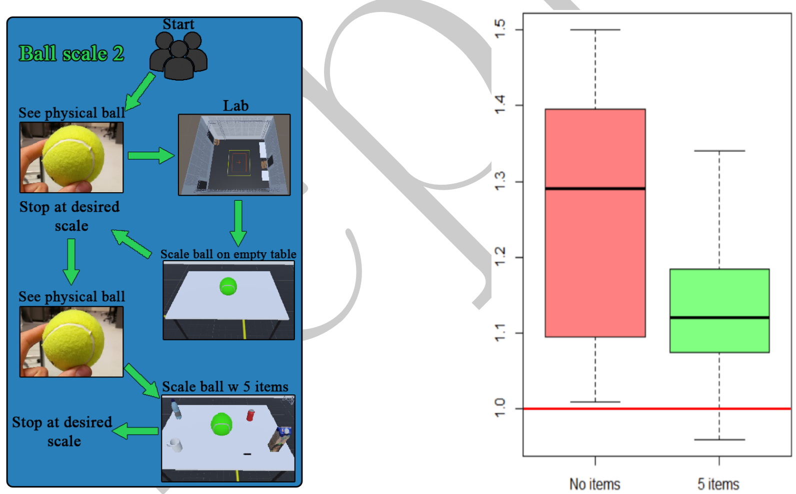
4.1 Familiar Objects as Visual Cues Setup

The first experiment focused on testing whether the different visual cues added to the scene improve user's perception of scale. A total of 15 students participated in the experiment, all of them naive users of VR, with normal or corrected-to-normal vision.

At the beginning of the test, the participants saw a physical ball and were put in the replica of the testing lab in VR. They were tasked with scaling a VR ball to its real world size, using the controller to make adjustments. After confirming, the facilitators noted down the size. Then the participants took of the HMD and were presented with the ball and table with 5 additional objects in the real world. The same items were displayed on the table in the VE in the corresponding locations. Participants were then instructed again to scale the ball and after confirming the test was concluded. Each time the ball started from a different size.

4.2 Results

The data was found to be approximately normally distributed through Shapiro-Wilk's test. A paired T-test between the two case - with and without visual cues, was conducted and results were found to be significant ($p=0.0256$, $p < 0.05$). A vast majority of the participants reported using the added objects as a point of reference when re-scaling the ball in the second part of the test.



(a) (b)

Fig. 3: Setup of the experiment 3a and the scale results in percentage from the first experiment, with and without items 3b. Red line shows correct scale.

The participants on average over-scaled the ball by 25% in the condition without the visual-cues and 14% with the visual-cues (Figure 3b). The difference in means suggests that adding visual cues to the virtual environment improves people's perception of scale, yet they still tend to over-scale the object. This general tendency to over-scale the object could mean that the participants try to compensate for the scale compression. This is further explored in the second experiment.

4.3 Transitional Environment and Tactile Augmentation Setup

The second experiment investigates how a transitional environment (TE) and tactile augmentation (TA) can further affect the users' perception of scale. A total of 40 participants have taken part in the experiment, 10 participants per condition in a between subject experiment. The participants are a combination of naive and experienced users and all have normal or corrected to normal vision.

The participants are tasked with scaling a bus they are in. The difference between the real scale of the bus and the participants' chosen scale is measured as accuracy. The test incorporates the model of the real laboratory as the TE, where users start the test, before being teleported to the bus model. The TA part of the experiments is in the form of a real bus chair and pole

The test is split into four conditions in order to evaluate separate and combined effects of TE and TA on scale perception, these will be referred to as A, B, C and D respectively going forth.

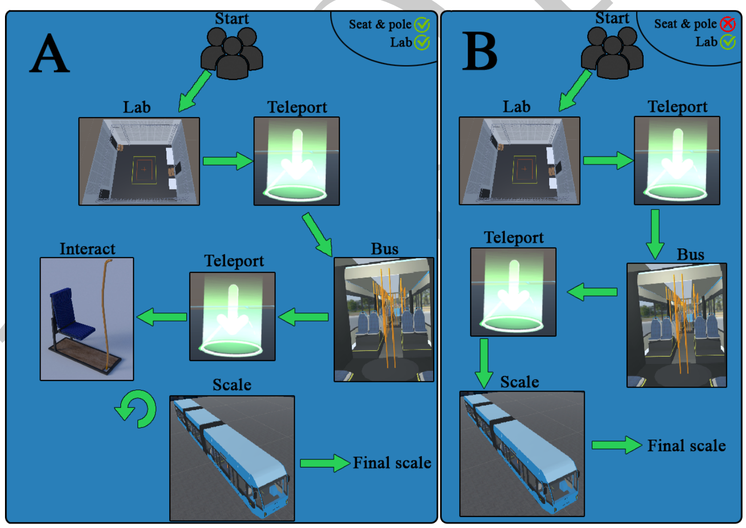


Fig. 4: Experimental Procedure for A and B conditions

The most complex setup is A (Figure 4a) where the participants are first put in the replica of the lab as their TE. They are instructed to teleport out of the room to the bus when they felt ready. In the bus they can move around using three fixed teleport points located in the back, middle, and front of the bus and move freely in short distances. They can freely interact with the TA objects which are located in a fixed position in the bus. Afterwards they are instructed to adjust the scale of the bus, until they feel it is right. The scaling is performed on the whole model of the bus, including the TA objects. After confirming the scale the test is concluded.

Condition B (Figure 4b) has the same procedure, excluding the interaction with the TA object. The model of the chair is still included in the bus environment, however the physical chair is not there for the participants to interact with. In the condition C (Figure 5c) the participants started the test already in the bus, without the use of TE, but are allowed to interact with the TA objects. The last condition D (Figure 5d) neither the TA or the TE are present, but the procedure stays the same.

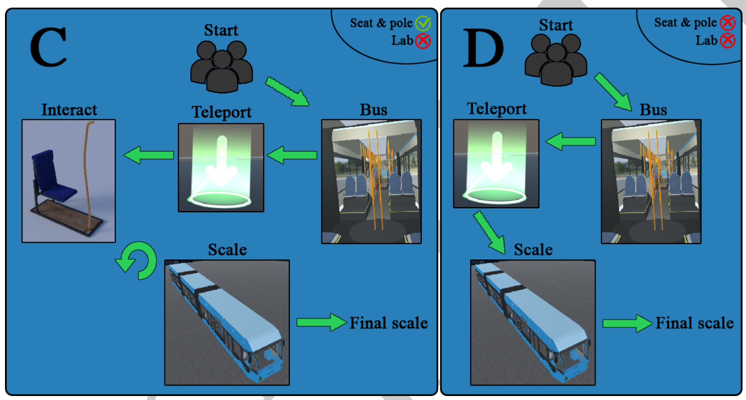
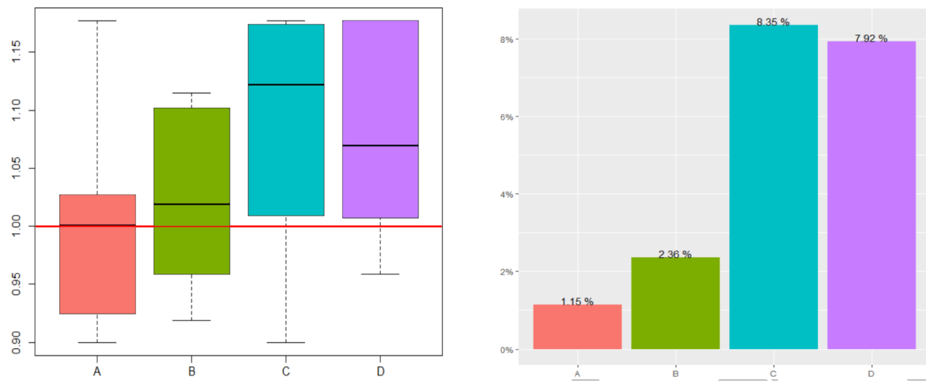


Fig. 5: Experimental Procedure for C and D conditions

4.4 Results

The Shapiro-Wilk test for normality showed that the data is approximately normally distributed for three out of the four groups. The p-values for Conditions A, B and C are 0.087(A), 0.437(B), 0.056(C) but for condition D it was 0.034(D), meaning that the data was not normally distributed. Furthermore, Levene's tests is performed, comparing condition A to B, C and D respectively, and confirmed that homogeneity requirements are met. The Kruskai-Wallis test is performed on the gathered data and the resulting p-value is found to be 0.211 ($p > 0.05$), meaning that no significant difference can be found. However, by looking at graphical representation of the data we can see that there is a difference between the means, as seen in Figures 6a and 6b.



(a) Bus scale in the four conditions, red line shows correct scale

(b) Mean difference from 1:1 scale in % for all four conditions

Fig. 6: Results from the second experiment. Even if the results are shown to have no statistical difference, the calculated means demonstrate positive effect of TA and TE.

The results suggest that the use of TE before entering a VR simulation improves scale perception among participants. Those exposed to the replica of the lab before entering the bus (A, B), were able to scale its size more accurately to its real-life size, while participants in the conditions without TE (C,D) tended to overscale the bus around them, further suggesting that they were compensating for the compression of scale. This tendency resulted in the non-normal distribution in Condition D where 4 out of 10 participants set the scale to its maximum, and some even expressed that they would scale it up more if allowed to. The results also show that TE affects perception of scale more significantly than the use of TA element.

5 Conclusion

In this paper we presented a user study conducted on various ways to improve the perception of scale in VR, in a context of visualizing bus models. We tested three common factors - adding visual cues, transitional environment and tactile augmentation.

We demonstrate that every day objects, as visual cues alleviate the problems with perceiving scale, but the scale compression is still a problem. A second experiment is conducted introducing a transitional environment and tactile augmentation, in the form of a 3D modeled laboratory and a bus chair and pole. We show that scale compression is mostly reverted using both and a transitional environment gives better results on its own. With this we shown that the topic is worth further investigation. As future work we would like to verify the results using more participants, as well as test with different representations of the three factors.

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